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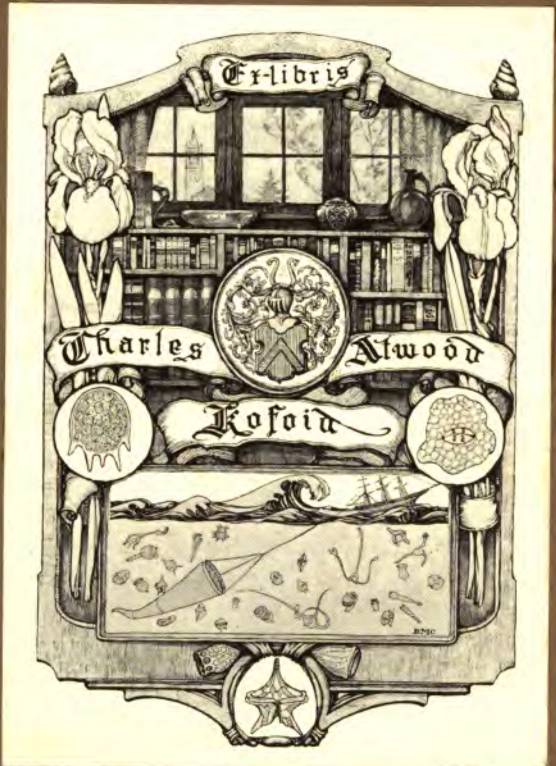
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ELECTRICAL PHENOMENA AND THEORIES.

NOTES

OF A COURSE OF SEVEN LECTURES ON

ELECTRICAL PHENOMENA

AND

THEORIES,

DELIVERED AT

THE ROYAL INSTITUTION OF GREAT BRITAIN

APRIL 28—JUNE 9, 1870.

BY

JOHN TYNDALL, LL.D. F.R.S.

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PREFACE.

THE reason assigned for the publication of my "Notes on Light" applies also to these Notes on Electricity. They are desired by persons interested in education.

I consign the proofs to the care of my friend Professor Goodeve prior to my departure for Switzerland. I have also to thank Mr. Vincent, Librarian of the Royal Institution, for his intelligent assistance.

JOHN TYNDALL.

ROYAL INSTITUTION,
June 29th, 1870.

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NOTES

ON

ELECTRICAL PHENOMENA AND THEORIES.

Voltaic Electricity: the Voltaic Battery.

1. If two pieces of the same metal (pure zinc or pure platinum for example) be immersed in water, which has been rendered sour by the addition of a little sulphuric acid, the acidulated water attacks neither.

The ordinary zinc of commerce being rendered impure by the admixture of other metals is attacked by the acid. It may, however, be enabled to withstand the acid by covering its surface with mercury. The zinc is dissolved by the mercury, detached from its impurities, and presented to the liquid. This process is called *amalgamation*.

2. If two pieces of two different metals (pure zinc and platinum for example) be immersed in acidulated water, no sensible action occurs *as long as the metals do not touch each other*; but the moment they touch, and as long as they continue in contact, the zinc is attacked by the acidulated water and dissolves, while bubbles of gas rise from the surface of the platinum.

3. This gas when collected proves to have the specific gravity of hydrogen; like hydrogen it also burns in the air. The water in fact is decomposed by the touching metals; its oxygen unites with the zinc to form oxide of zinc, while its hydrogen escapes from the platinum.

4. If the two metals be only partially plunged into the acidulated water, it does not matter whether contact occurs *within* the liquid or *outside* of it. The effect in both cases is the decomposition of the water, the solution of the zinc, and the liberation of the hydrogen gas.

5. When the two partially immersed metals are connected outside the liquid by a long wire (say of copper), the effect is the same as when they touch directly. In both cases a *circuit* is said to be formed, consisting of the two metals and the liquid. In the case last mentioned the copper wire is said to complete the circuit.

For these experiments a strip of platinum and a strip of amalgamated zinc are employed. The liquid is placed in a glass cell with parallel sides through which is sent a beam of light, and by means of a lens a magnified image of the cell and its two strips is cast upon

a screen. The chemical action consequent upon touching the metals, or on completing the circuit with a wire, and its suspension when contact is interrupted, are then very plainly seen.

6. The wire is also said to be the vehicle of an *electric current* which flows round the circuit. It is also called a Voltaic current, because the action here described was discovered by the celebrated Italian philosopher Volta. These terms, however, convey to us, as yet, no meaning. Our sole business during the present lecture is to examine the wire which completes the circuit, and to determine wherein it differs from an ordinary wire.

7. And to enable ourselves to do this effectually, we shall employ an arrangement, or a combination, of zinc and platinum plates and acids, known as a voltaic battery. We shall subsequently analyze this battery, and determine what occurs within it. For the present, as aforesaid, we shall confine ourselves to the examination of the wire which completes the circuit outside the battery.

Electro-Magnetism: Elementary Phenomena.

8. Interrupting the circuit, and immersing the wire in iron filings, it shows no power of attraction over them. Establishing the circuit, on re-immersing the wire in the filings they cluster round it and cling to it. If the wire be raised out of the filings, they form an envelope round it. The moment, however, the circuit is interrupted, the filings fall.

9. If the wire be disconnected from the plates of platinum and zinc, and stretched under and parallel to a suspended bar magnet, no action is observed; but on making the wire, stretched beneath the magnet, form part of a voltaic circuit, the magnet is deflected from the magnetic meridian. This is Œrsted's discovery.

10. To the eye the wire, if tolerably thick, is unchanged by its connection with the zinc and platinum. But if for the thick copper wire a thin platinum wire be substituted it is sensibly heated, and may even be caused to glow brightly. The wire therefore must be the vehicle of some power or condition which is competent to produce both magnetic and thermal phenomena.

11. If a naked wire, forming part of a voltaic circuit, be wound round a bar of iron, the power of which the wire was the vehicle is in great part transmitted to the iron which becomes part of the circuit.

12. But if the wire be overspun with cotton, or still better with silk, this transmission of the power from the wire to the iron bar is prevented. The wire may then be coiled round the bar while the power is compelled to pass in succession through all the convolutions of the wire. Here the iron bar is not at all in the circuit.

13. But though not in the circuit it is powerfully excited by the surrounding wire. Every convolution of the wire evokes a certain amount of *magnetism* in the bar; and by rendering the convolutions

sufficiently numerous, a magnet of enormous strength may be thus generated. This is Sturgeon's application of Arago's discovery.

14. Such a magnet is called an Electro-magnet, to distinguish it from ordinary permanent steel magnets. When the circuit is broken, the power of the electro-magnet ceases. It then falls from its highly excited condition to the condition of ordinary iron.

15. For electro-magnetic purposes the covered wire is usually coiled round a hollow reel, several layers of coils being sometimes superposed upon each other. In this condition the reel is called an *electro-magnetic helix.* The iron bar to be magnetized is placed within the helix, forming its *core.* The electro-magnet may be either straight, shaped like a horseshoe, or it may be caused to assume other forms.

16. The smooth bar of iron placed across the ends, or poles, of a horseshoe magnet is sometimes called a *keeper*, sometimes an *armature*, and sometimes a *sub-magnet.*

17. It is not necessary that the convolutions of the helix should be close to the core. A hoop, for example, a yard in diameter, round which covered wire is coiled, magnetizes an iron bar placed across it at its centre. The magnetized body is here nearly 18 inches from the magnetizing coil. How is the power transmitted from the one to the other? Is it an action at a distance, or does it require a medium for its propagation? I do not know. The question at present profoundly interests investigators.

18. If a covered wire forming part of a voltaic circuit be coiled round an iron bar near one of its ends, there is a propagation of the excitement along the bar towards the distant end. As the coils augment in number the attractive power of the distant end increases. On undoing the coils, the magnetism gradually falls. The process resembles more or less the conduction of heat. The augmentation of the coils answering to the increasing of the temperature, and the undoing of the coils answering to the cooling of the end of the bar.

Electro-Magnetic Engines.

19. When the end of a cylinder of iron is partially introduced into an electro-magnetic helix, on completing the circuit a force of suction is exerted upon it tending to draw it into the helix. Page turned this force to account in the construction of an electro-magnetic engine.

Hollow iron cylinders, which pass freely into the helix, are employed for this experiment. The end only of the hollow cylinder being introduced, when the circuit is completed the cylinder is suddenly and strongly sucked in.

20. Others have turned to account mechanically the attraction exerted by electro-magnetic cores on bars of iron. The distinguished electro-mechanician Froment produced rotatory motion in this way. A series of electro-magnets are so ranged that their poles lie facing each

other along the circumference of a circle; and a series of transverse bars of iron are so connected together as to be able to approach the poles in succession, and rotate as a system. When the circuit is established, these bars are attracted, motion being thus imparted to the system. The bars, on arriving at the poles which attract them, suddenly cease to be attracted; the magnetism being temporarily suspended to allow each bar to pass forward, with the velocity impressed upon it, to the next pair of attracting poles. On reaching these the magnetism is again temporarily suspended. Thus the bars *are never pulled back*; and in this way a continuous motion of rotation is maintained.

21. This rotatory motion can be applied in various ways; it may, for example, be caused to pump water, to saw wood, or to drive piles.

One of Froment's electro-magnetic engines, and its application to pumping and pile-driving, is employed to illustrate this.

Physical Effects of Magnetization.

22. Sound is one of the physical effects which accompany sudden magnetization and sudden demagnetization. An ear placed close to an iron core hears a clink the moment the circuit is established round it. A clink is also heard when the circuit is broken. This is Page's discovery. Employing a contact-breaker (in a distant room to abolish its noise), the coil may be magnetized and demagnetized in quick succession; the sounds then produced may be heard by several hundreds at once.

A poker of good soft iron placed within an electro-magnetic helix, and with its two ends supported on wooden trays, produces a very good effect. The sound may be rendered musical.

23. When an iron bar is magnetized, its volume is unchanged, but its shape is altered. It lengthens in the direction of magnetization. This is Joule's discovery.

24. Joule employed a system of levers to augment the effect, and a microscope to observe the elongation thus augmented. Our method is this:—The iron bar is magnetized by an electro-magnetic helix which surrounds it. Its elongation is first augmented fiftyfold by means of a lever; and this motion is applied to turn the axis of a rotating mirror. From the mirror is reflected a long beam of light, which forms an index without weight. The reflected beam may be caused to print a circle of light upon a white screen, and this circle, when the bar is magnetized, suffers a displacement due to the elongation of the bar. This displacement may amount to a foot or more.

What is the cause of this elongation? The discussion of this question requires some preliminary knowledge.

25. If a sheet of paper or a square of glass be placed over a magnet, iron filings scattered on the paper or on the glass arrange themselves

in lines which Faraday called Lines of Force. Along these lines the filings set their longest dimensions, and they also attach themselves end to end. A little bar of iron, or a small magnetic needle, freely suspended, sets itself also along these lines of force.

The formation and modifications of the magnetic curves, or lines of force, are shown in this lecture by means of small magnets held between plates of glass and strongly illuminated. Magnified images of the curves are thrown upon a screen about 40 feet distant. The shifting of the curves by the tapping of the glass is plainly visible.

26. We may regard a bar of iron as made up of particles united by the force of cohesion, but still to some extent distinct. When iron is broken we see crystalline facets on the surface of fracture. In fact the bar is composed of minute crystals of irregular shape. These, when the bar is magnetized, try to set their longest dimensions parallel to the direction of magnetization, that is to say, in the direction of the bar itself. They succeed in this effort to some slight extent, and thus produce the minute and temporary lengthening of the bar. This is the explanation of De la Rive. It is, I think, as true as it is acute.

27. Magnetic oxide of iron may be suspended as a powder in water contained in a cylindrical vessel with flat glass ends. Let the vessel be surrounded by a coil of covered wire. Looking at a candle through the muddy liquid, and making the coil part of a voltaic circuit, the candle brightens at the moment the circuit is made. Breaking the circuit, dimness again supervenes. This is due to an arrangement of the particles of suspended oxide similar to that of the iron filings. They set their longest dimensions parallel to the beam of light, and thus obstruct its passage less. They also attach themselves end to end, and form lines like the lines of filings. This beautiful experiment is due to Grove.

Projecting a magnified image of the end of the cylindrical cell on a screen, and sending through it the beam of the electric lamp whenever the circuit is established, an illuminated disk, 2 or 3 feet in diameter, flashes out upon the screen.

Character of Magnetic Force.

It is necessary to our further progress to have clear and definite ideas as to the character of the magnetic force.

28. The magnetic power of a magnet, or of a magnetic needle, though really distributed throughout its mass, appears to be concentrated at two points near the ends. These points are called the *poles* of the magnet or needle.

29. The magnetic power of the earth is doubtless also distributed through the mass of the earth, but a concentration similar to that just noticed endows the earth also with magnetic poles.

30. The action of the earth upon a magnetic needle is this: the north terrestrial pole repels one end of the needle and attracts the

other: the south magnetic pole also attracts one end of the needle and repels the other. But the end attracted by the north terrestrial pole is repelled by the south, while the end attracted by the south is repelled by the north.

31. Thus to each terrestrial magnetic pole the needle presents two ends which are differently endowed. Two opposite kinds of magnetism may be supposed to be concentrated at the two ends. In this *doubleness* of the magnetic force consists what is called *magnetic polarity.*

32. Each of the two distinct kinds of magnetism may be regarded as self-repellent. North repels north, and south repels south. But different kinds of magnetism are mutually attractive; south attracts north, and north attracts south.

33. When a magnet, or a magnetic needle, is suspended with the line joining its poles *oblique* to the magnetic meridian, the earth's action on the needle resolves itself into what in mechanics is called "a couple," tending to turn the needle into the magnetic meridian.

34. When the needle is in the meridian, the two forces which constitute the couple are opposite and equal. The tendency to produce rotation then ceases; the needle is in its position of equilibrium.

35. When the forces are equal and opposite they must neutralize each other; no *motion of translation* of the needle being, therefore, possible. Thus, when the needle is caused to swim on water, or on mercury, it does not move towards either of the terrestrial magnetic poles.

36. One pole of a bar magnet repels the one end and attracts the other end of a magnetic needle. At the other pole of the magnet the attraction and repulsion are reversed. In the middle of the magnet is the *magnetic equator*, where neither end of the needle is attracted or repelled.

Magnetism of Helix: Strength of Electro-Magnets.

37. An electro-magnetic helix, even without a core of iron, behaves exactly like a magnet. It attracts iron. Its two ends, moreover, are opposite poles, and between them is a magnetic equator. When, however, a core is placed within the helix, the magnetism of the combined system is far more intense than that of the helix alone.

38. The strength of a magnet is measured by its power to deflect a magnetic needle from its meridian; the magnetic strength of a helix alone, and of a helix and core combined, are similarly determined.

39. To obtain the magnetic strength of the core alone, we first determine the strength of the helix alone, then that of the helix and core combined; subtracting the former strength from the latter, we obtain the magnetic strength of the core.

40. If the cores be thick and formed of good iron, the magnetic strength of the core is exactly proportional to that of the helix. A helix of double power will produce an electro-magnet of double

strength; a helix of treble power, an electro-magnet of treble strength, and so on. Thus by varying the strength of the helix we vary in like degree the strength of the iron core within it.

Electro-Magnetic Attractions: Law of Squares.

41. And here an important point arises. When we allow a core of double power to act upon a piece of good iron, nearly, but not quite in contact with the core, the attraction of the iron is not doubled, but quadrupled. If the core be of treble power, the attraction is not only trebled, but it increases ninefold. If the magnetic strength of the core be quadrupled, the attraction of the iron is augmented sixteenfold. In fact the attraction is proportional, not to the strength simply, but to the strength multiplied by itself, or to the *square of the strength* of the electro-magnet.

We must be very clear as to the cause of this action, and must therefore contrast for a moment the magnetic action of hard steel with that of soft iron.

42. Soft iron is easily magnetized, but it loses its magnetism when the magnetizing force is withdrawn. Steel is magnetized with difficulty, but it retains its magnetism even after the withdrawal of the magnetizing magnet.

43. This obstinacy on the part of steel in declining to accept the magnetic state, and this retentiveness on the part of steel when the magnetic condition has been once imposed upon it, are called *coercive force.* It is not a happy term, but it is the one employed.

44. Supposing a piece of magnetized steel to possess a coercive force so high as to resist further magnetization, its attraction by an electro-magnet would be directly proportional, not to the square of the strength, but simply to the strength of the electro-magnet.

45. Why then does the iron follow the law of the square of the strength? It is because the magnetic condition of the iron is not constant, but rises with the strength of the magnet. When the magnetism of the core is doubled, the magnetism of the iron is also doubled; when the magnetism of the core is trebled, the magnetism of the iron is trebled. The resultant attraction is found by multiplying the magnetism of the iron by the magnetism of the core, and this product is the expression of the law of squares just referred to.

46. To make the matter clearer, let us figure the magnetism of the core as due to particles of magnetism, which are introduced into the core in gradually increasing numbers. Let us start with a core possessing one magnetic particle, and let it act upon a piece of hard steel also possessing one magnetic particle; the resulting attraction will be unity or 1. Let two particles be now thrown into the core: the steel in virtue of its coercive force remains unchanged, but its particle being now pulled by two particles instead of one, the resulting attraction will be 2. If three particles of magnetism be thrown into the

core, all of them pulling at the single particle of the steel will produce a treble attraction and so on.

47. Now let us start with a core possessing, as before, a single particle of magnetism, and with a piece of iron also possessing a single particle generated by the core; the attraction as before is here unity. On introducing two particles into the core, they generate immediately two particles in the iron. But two particles each pulled by twice the force first exerted, makes the attraction four times what it was at the outset.

It is to be remembered that every particle is attracted as if the other particles were absent.

48. In like manner, if three particles be thrown into the core, three particles are also generated in the iron. Each of these iron magnetic particles is pulled by the three particles of the electro-magnet: that is to say, each of the iron particles is pulled with three times the primitive force. But there are three particles so pulled; hence the attraction is nine times what it was at the outset.

49. Let us compare this action for a moment with that of gravity. Two masses of matter attract each other with a force which we shall take as our unit. If the one mass be doubled, the attraction is doubled; if both masses be doubled, the attraction is increased fourfold. If one mass be trebled, the attraction is trebled; if both masses be trebled, the attraction is increased ninefold. When, therefore, both the masses are doubled and trebled, we have the law of squares. Now, it is this doubling and trebling, *in both cases*, of the thing which causes magnetic attraction, which causes it to follow the same law.

Inference from Law of Squares: Theoretic Notions.

50. Why do I lead you through these considerations? Simply to make clear to you, that if "the law of squares" here developed show itself in the action of a magnet upon matter, we may infallibly infer that the condition of that matter is not *a constant condition;* but that it rises and falls with the condition of the magnet. Matter thus affected is said to be magnetized by influence or by induction. It is attracted or repelled (for we shall come immediately to the repulsion of matter by a magnet) in virtue of some condition into which it is temporarily thrown by the influencing magnet.

51. What then is the thing that causes magnetic attraction? The human mind has long striven to realize it. Thales (600 B.C.) thought that the magnet possessed a soul. Cornelius Gemma in 1535 supposed invisible lines to stretch from the magnet to the attracted body, a conception which reminds us of Faraday's Lines of Force. Others thought the iron the natural nutriment of the magnet. Descartes embraced magnetic phenomena in his celebrated theory of vortices, and in our day Clerk Maxwell has worked in this direction. Æpinus assumed the existence of a magnetic fluid. Coulomb assumed the

existence of two fluids, each self-repellent, but mutually attractive. Ampère deemed a magnet an assemblage of minute electric currents, which circulated round the atoms of the magnetized body. These conceptions are sometimes exceedingly useful as a means of connection and classification, even when we do not believe them true. William Thomson deduces magnetic phenomena from "imaginary magnetic matter," thus giving the mind the conception while distinctly releasing it from belief. The real origin of magnetism is yet to be revealed.

Diamagnetism : Magne-Crystallic Action.

52. Brugmans, in 1778, first observed the repulsion of bismuth by a magnet. In 1827 Le Baillif described the repulsion of antimony. Saigey, Seebeck, and Becquerel also observed certain actions of the kind.

53. In 1845 Faraday generalized these observations by demonstrating the magnetic condition of all matter. He showed that bodies divided themselves into two great classes, the one attracted, the other repelled by the poles of a magnet.

54. To the force producing this repulsion, Faraday gave the name of Diamagnetism.

What is the nature of this force? Is it inherent and constant, or is it induced?

55. The repulsion of diamagnetic bodies follows accurately the law of squares above developed. A double force produces a quadruple repulsion; a treble force produces a ninefold repulsion, and so on.

56. Hence we may infer, with certainty, that the condition of diamagnetic bodies in virtue of which they are repelled by a magnet, is a condition induced by the magnet, rising and falling as the strength of the magnet rises and falls.

57. The force of diamagnetism is vastly feebler than that of ordinary magnetism. Of all diamagnetic substances, for example, bismuth is the most strongly repelled; but its repulsion is almost incomparably less than the attraction of iron. According to Weber, the magnetism of a thin bar of iron exceeds the diamagnetism of an equal mass of bismuth about two-and-a-half million times.

58. Diamagnetic bodies under magnetic excitement exhibit a polarity the reverse of that of magnetic bodies. In all cases whether we operate with helices or with magnets, or with helices and magnets combined, the actions of magnetic and diamagnetic bodies are antithetical.

59. An iron statue standing erect on the earth's surface is converted into a magnet by the earth's magnetism; a marble statue, or a man standing erect, is converted by the same force into a diamagnet; for marble is diamagnetic, and so are all the tissues and all the solids and fluids of the human body. The poles of the man are those of the iron statue reversed.

60. Organic bodies, and most crystals, are magnetized with different degrees of intensity in different directions. They are endowed with *axes* of magnetic induction.

61. Thus in the case of Iceland spar (carbonate of lime), the *repulsion* along the axis is a maximum. In the case of carbonate of iron, a crystal of the same shape and structure as carbonate of lime, the *attraction* along the axis is a maximum.

62. The position assumed by a crystal when suspended between the poles of a magnet, depends on its magnetic axes.

Frictional Electricity: Attraction and Repulsion: Conduction and Insulation.

63. By the friction of a woollen cloth amber is endowed with the power of attracting light bodies. This substance was called Electron by the Greeks; hence the name Electricity was applied to the power of attraction exhibited by amber. This attraction remained an isolated fact for more than 2000 years.

64. In the year 1600 Dr. Gilbert of Colchester, physician to Queen Elizabeth, showed that the power of attraction was shared by many other substances. Dry glass, for example, when rubbed by silk, and dry sealing-wax when rubbed by flannel, exhibit this attractive power. When they do so they are said to be *electrified.*

65. An electrified body attracts and is attracted by all kinds of unelectrified matter; but *repulsion* may also come into play. Thus, rubbed glass *repels* rubbed glass, and rubbed sealing-wax repels rubbed sealing-wax; while rubbed glass attracts rubbed sealing-wax, and rubbed sealing-wax attracts rubbed glass.

66. Hence the notion of *two kinds* of electricity, one proper to vitreous bodies, and therefore called vitreous electricity; the other proper to resinous bodies, and therefore called resinous electricity.

67. These terms are improper; because by employing suitable rubbers we can obtain the electricity of sealing-wax from glass, and the electricity of glass from sealing-wax. We now use the term *positive* electricity to denote that developed on glass by the friction of silk; and *negative* electricity to denote that developed on sealing-wax by the friction of flannel.

68. Bodies endowed with the same electricity repel each other, while bodies endowed with opposite electricities attract each other. This is the fundamental law of electric action.

69. The rubber and the body rubbed are always endowed with opposite electricities. They always attract each other. The work done in overcoming this attraction appears as heat in the electric spark.

70. To find the kind of electricity with which a body is endowed we must ascertain, by trial, the electricity by which the body is *repelled.* This, we may be sure, is the electricity of the body. *Attraction* does not furnish a safe test, because unelectrified bodies are attracted.

71. Some substances possess in a very high degree the capacity of transmitting the electric power, or condition; others possess in a high degree the capacity of intercepting it. The former bodies are called *conductors*, the latter bodies, *insulators*.

72. The insulators were formerly called *electrics*, because they could be electrified by friction *when held in the hand*. The conductors were called *non-electrics*, because they could not be so electrified. The division is improper, because if a conductor be insulated it can readily be electrified. To keep it electrified, an insulator must be introduced between it and the earth.

Theories of Electricity: Electric Fluids.

73. What is electricity? Why should it adhere so tenaciously to some substances, and flow so freely through or along others? The human mind has made many attempts to imagine the inner cause of electric action, and it still continues to make such attempts. Formerly it was thought that magnetism and electricity, as well as light and heat, were all the work of "imponderable matter," associated with the ordinary matter. In the case of light and heat, this conception has undergone profound modification; and we seem to see clearly the mechanical cause of both. But no similar clearness has as yet been attained with regard to electricity, though a strong presumption exists that our notions of it are destined soon to undergo a modification equally profound.

74. Meanwhile we may employ the provisional conception furnished by the *theory of electric fluids*. It will enable us to classify our facts, though it is not to be regarded as demonstrated.

75. According to this theory, electrical attractions and repulsions arise from two invisible fluids, each self-repulsive, but both mutually attractive. The fluids are supposed to be mixed together to form a compound neutral fluid in unelectrified bodies.

76. The act of electrification by friction consists in the forcible separation of the two fluids, one of which is diffused over the rubber, and the other over the body rubbed. But they may also be separated in another way, now to be illustrated.

Electric Induction: the Condenser: the Electrophorus.

77. If an electrified body be brought near an insulated unelectrified conductor, but not into contact with it, the electrified body will decompose the compound fluid of the conductor; attracting one of its constituents and repelling the other. When the electrified body is withdrawn, the separated fluids reunite and neutralize each other.

78. This forcible separation of the two fluids of a neutral conductor, by the mere proximity of an electrified body, is called *electric induction*. Bodies in this state are also said to be electrified by *influence*. Neutral bodies are attracted because they are first excited by induction.

79. When an insulated conductor is acted on by an electrified body, its repelled electricity is free, but its attracted electricity is held captive by the inducing electrified body. Connecting the conductor for a moment with the earth, its free electricity escapes; and then, on the removal of the electrified inducing body, the captive electricity is liberated and diffused over the surface of the conductor.

80. Thus by the mere proximity of the electrified body, and without establishing contact between it and the neutral conductor, we can charge the latter *with the opposite electricity.*

81. Two sheets of tinfoil (conductors) being separated from each other by a sheet of glass (an insulator), if one sheet have electricity imparted to it, it will act through the glass, and decompose the neutral electricity of the opposite sheet, attracting the one constituent and repelling the other.

82. If the second sheet be connected with the earth, the repelled electricity will flow away, and we shall have two mutually attractive layers of electricity separated from each other by the glass.

83. If the one sheet of tinfoil be united with the other by a conductor, the two opposite electricities will flow together; the tinfoil is then said to be discharged. This discharge usually assumes the form of a spark.

84. If the surface of a cake of resin, or of a sheet of vulcanized india-rubber be electrified, a plate of metal laid upon it will have its neutral fluid decomposed; its positive fluid being attracted and its negative repelled. On touching the metal plate its free (repelled) electricity flows to the earth; and now, if the plate be raised by an insulating handle, it will appear charged with positive electricity. This is the principle of the *Electrophorus.*

The Electric Machine: the Leyden-jar.

85. An Electric Machine consists of two parts: the insulator, which is excited by friction, and the prime conductor.

86. The first electric machine consisted of a ball of sulphur, which was rubbed against the hand. It was invented by Otto Von Guericke, burgomaster of Magdeburg, in the year 1671. A sphere of glass was afterwards introduced, then a cylinder of glass, and finally a round glass plate, which was rubbed with dry silk.

87. The prime conductor is thus charged: When the glass plate is turned by a handle it passes between the silk rubbers, and is positively electrified. The electrified glass then acts by induction upon the prime conductor, attracting the negative electricity, and repelling its positive. The conductor is furnished with points, from which the negative electricity streams out against the excited glass. Thus, the prime conductor is charged, not by directly communicating to it positive electricity, but by robbing it of its negative, the positive remaining behind.

88. The arrangement mentioned in Note 81 is virtually a Leyden-jar. Were the plate of glass there referred to moulded into the shape of a jar, one sheet of foil would cover its interior and the other its exterior. When the jar is connected with an electric machine, its charged interior coating acts by induction across the glass on the exterior coating, attracting the opposite and repelling the similar electricity.

89. In the experiment which led to the discovery of the Leyden-jar *the hand of the experimentalist* served as the outer coating.

90. The escape of the repelled electricity of the outer coating to the earth leaves the captive electricity exposed solely to the attraction of that within the jar, and enables the jar to take a strong charge.

The Electric Current.

91. When the outer and the inner coatings are connected by a conductor, *an electric current* passes from the one to the other.

92. The current starts at the same instant from the inner and outer coatings; the *middle* point of the conductor being reached last by the current. This indicates that there are *two* currents which start at the same moment from the inner and outer coatings.

93. It is agreed to call the direction in which the *positive* electricity flows *the direction of the current.*

The Electric Discharge: Thunder and Lightning.

94. When an electric current encounters resistance in its passage, heat is developed: this heat is sometimes so intense as to reduce metals to a state of vapour.

95. When a body is intensely electrified it will discharge its electricity to an unelectrified body across an interval of air in the form of an electric spark. Two bodies oppositely electrified discharge to each other in the same way.

96. When two oppositely electrified clouds discharge towards each other, the track of the lightning marks the course of an electric current, and the sound of the thunder is the sound of an electric spark.

97. An electrified cloud, if it come near the earth, may discharge its electricity to the earth in the same way.

98. If the body through which the atmospheric electricity passes be a good conductor, and of sufficient size, no harm is done; but the *resistance* offered by trees, houses, and animals to the passage of the electricity usually causes their destruction.

99. The nervous system requires a certain interval of time to become conscious of pain. The time of an electric discharge is but a small fraction of this interval; hence as a sentient apparatus the nervous system is destroyed before consciousness can set in. If this be true—and there are the strongest grounds for believing it to be true—death from lightning must be painless.

100. When an electrified cloud passes over a pointed lightning-conductor, the opposite electricity of the earth is discharged from the point of the conductor against the cloud. The cloud is thus neutralized, and, in general, without producing thunder.

101. The duration of an electric spark amounts only to an extremely small fraction of a second. On this account, when moving bodies are suddenly illuminated by the spark from a Leyden-jar, they appear to *rest* for a short interval in the position which they occupied when the flash fell upon them. A moving cannon-ball illuminated by a flash of lightning appears to stand still for about one-eighth of a second, this being about the interval during which an impression, once made, persists upon the retina.

102. The unretarded electric spark will scatter gunpowder, but will not ignite it. To produce ignition it is necessary to retard the discharge by sending it through a wet string.

Electric Density: Action of Points.

103. If we double the quantity of electricity imparted to the same conductor, the density of the electricity is said to be doubled; if we treble the quantity, the density is said to be trebled; and so on.

104. On a *sphere* the density of the electricity is the same at all points of its surface; on a *plate* the density is greatest at the edges; and on an elongated conductor the density is greatest at the ends.

105. When the conductor ends in a sharp point the electric density at the point is so great that the electricity discharges itself into the air.

106. The air thus electrified is self-repellent, and is also repelled by the point, the so-called "electric wind" being produced.

107. By causing an electric wind to issue from opposite points of a light body, the reaction of the two winds may make the body to float in stable equilibrium in the air.

Relation of Voltaic to Frictional Electricity.

108. The outer ends of two pieces of zinc and platinum, partially immersed in acidulated water, are in opposite electrical conditions. The free platinum end shows positive electricity, while the free zinc end shows negative electricity.

109. When both plates are united by a wire, the positive flows along the wire towards the negative, and the negative towards the positive. But, as mentioned in Note 93, it is agreed to call the direction in which the positive electricity flows *the direction of the current.*

110. The force which urges this current forward (the electromotive force) is enormously less than that which urges forward a current of frictional electricity. The consequence is that the latter

is able to surmount resistances which are totally unsurmountable by the former.

111. But by linking cells together we cause the voltaic current to approach more and more to the character of the frictional current. It requires, however, a battery of more than a thousand cells to make the current from a voltaic battery jump over an interval of air $\frac{1}{1000}$th of an inch in length. An electric machine of moderate power, and furnished with a suitable conductor, is competent to urge its current across an interval ten thousand times as great as this.

112. The electric spark passes through air by the agency of the particles of the conductor from which it springs, and which are carried forward by the discharge.

113. But measured by other standards the frictional current is almost incomparably more feeble than the voltaic current. For example, it is not without special arrangements for multiplying the effect that the current from a large electrical machine is enabled to deflect a magnetic needle.

114. Faraday immersed two wires, the one of zinc and the other of platinum, each $\frac{1}{18}$th of an inch in diameter, in a cell of acidulated water. The depth of immersion was only $\frac{5}{8}$ths of an inch, and the time of immersion only $\frac{3}{20}$ths of a second. Still he found that the electricity generated by this small apparatus, in this brief time produced a distinctly greater effect upon a magnetic needle than 28 turns of the large electric machine of the Royal Institution.

115. A cubic inch of air, if compressed with sufficient power, may be able to rupture a very rigid envelope; while a cubic yard of air, if not so compressed, may exert but a feeble pressure upon the surfaces which bound it. Now the electricity of the machine is in a condition analogous to the compressed air. Its density, or as it is sometimes called, its intensity, or tension, is great. The electricity from the voltaic battery on the other hand resembles the uncompressed air. It exceeds enormously in *quantity* that from the machine; but it falls enormously below it in intensity.

116. The deflection of a magnetic needle and other actions of the voltaic current depend solely upon quantity, hence the vast superiority of the voltaic current in producing such deflection.

117. Faraday found the quantity of electricity disengaged by the decomposition of a single grain of water in a voltaic cell (see Note 5) to be equal to that liberated in 800,000 discharges of the great Leyden battery of the Royal Institution. This, if concentrated in a single discharge, would be equal to a great flash of lightning. He also estimated the quantity of electricity liberated by the chemical action of a single grain of water on four grains of zinc to be equal in quantity to that of a powerful thunderstorm.

118. Weber and Kohlrausch have found that the quantity of

electricity associated with one milligramme of hydrogen in water, if diffused over a cloud 1000 mètres above the earth, would exert upon an equal quantity of the opposite electricity at the earth's surface an attractive force of 2,268,000 kilogrammes.*

Historic Jottings, concerning Conduction and the Leyden-jar.

119. In 1729, Stephen Grey, pensioner of the Charter House, discovered electric conduction. Connecting an end of a wire 700 feet long with a glass tube and supporting the wire on loops of silk, he found that on rubbing the tube the distant end of his wire became electrified and attracted light bodies. He also found that a wire loop did not answer as a support, as the electricity escaped through it; hence arose the division of bodies into conductors and insulators. Grey's observations were written down by the Secretary of the Royal Society the day before his death.

120. In October, 1745, Von Kleist, a bishop of Cammin, in Pomerania, charged with electricity a flask containing sometimes mercury, sometimes alcohol. Through a cork in the neck of the flask passed an iron nail, which was brought into contact with the conductor of an electrical machine. On touching the nail Von Kleist experienced a violent shock.

121. In January, 1746, Cunæus of Leyden received also a shock, and his experiment was repeated by Allamand and Musschenbroek. A wire passed from the conductor of the machine into a flask filled with water. Musschenbroek held the flask in the right hand, the machine was turned, and then with the left hand he drew a spark from the conductor. The shock received was, according to Musschenbroek, so terrible, that he declared he would not receive a second for the crown of France. Musschenbroek observed that it was only the person who held the flask in his hand that felt the shock. Kleist failed to recognize this condition.

122. In Germany the jar is sometimes called Kleist's jar, but more commonly, because of the failure just referred to, the Leyden-jar. The theory of it, and other similar apparatus, was given by Franklin in September, 1747. (See Notes 81, 88, 89, 90.)

123. In 1747, Dr. Watson, Bishop of Llandaff, sent the discharge from a Leyden-jar through 2800 feet of wire, and through the same distance of earth. Subsequently, in the same year, he sent the discharge through 10,600 feet of wire, supported by insulators of baked wood. The experiment was made on Shooter's Hill.

124. In 1748 similar experiments were made by Franklin across the Schuylkill, and by De Luc across the Lake of Geneva.

* The mètre is a yard and one-eleventh in length; the milligramme is $\frac{1}{65}$th of a grain; the kilogramme is 2 lbs. $3\frac{1}{4}$ oz.

Historic Jottings, concerning the Electric Telegraph.

125. The first proposal of an electric telegraph was made by an anonymous contributor to the 'Scot's Magazine' for 1753. Various attempts to apply frictional electricity for this purpose were subsequently made. They culminated in the exceedingly ingenious arrangement of Mr., now Sir Francis Ronalds, published in 1823.

126. The voltaic pile was described by Volta in a letter to Sir Joseph Banks, written from Como in 1800.

127. Immediately afterwards Nicholson and Carlisle discovered the decomposition of water by the voltaic current.

128. In 1800 Sömmering proposed a system of telegraphy based on the discovery of Nicholson and Carlisle. A similar system was proposed about the same time by Prof. Coxe, of Pennsylvania.

129. In 1820 Œrsted discovered the deflection of a magnetic needle by an electric current.*

130. The idea of employing the deflection of the needle for telegraphic purposes occurred to the celebrated French mathematician, La Place; the problem was partly worked out by Ampère, and still further advanced by Ritchie, Professor of Natural Philosophy in the Royal Institution.

131. In 1832 Baron Schilling constructed models of a telegraphic apparatus which were exhibited before the Emperors Alexander and Nicholas.

132. In 1833 Gauss and Weber established an electric telegraph between the Physical Cabinet and the Astronomical and Magnetic Observatories of Göttingen, embracing a distance of nearly 10,000 feet. Faraday's electricity instead of Volta's was employed by Gauss and Weber.

133. Steinheil was requested by Gauss to pursue the subject. To the telegraph he made many highly important contributions and suggestions. In 1837 he had established a system of wires about 40,000 feet in length, connecting various points in the city of Munich and its neighbourhood. The most considerable discovery of Steinheil, and indeed one of the most practically important hitherto made in connection with telegraphy, is that the "return wire" between two stations might be dispensed with, and the earth employed in its stead.

134. In 1834 Wheatstone, by means of a rotating mirror, made his celebrated experiments on the velocity of electricity. In the following

* In his exceedingly useful little book on the Telegraph, published in Weale's 'Rudimentary Series,' Mr. Robert Sabine quotes the following remarkable passage from a work on magnetism, published in Paris, by Professor Izarn, in 1804:—" D'après les observations de Romagnési, physicien de Trente, l'aiguille déjà aimantée, et que l'on soumet ainsi au courant galvanique, éprouve une déclinaison; et d'après celles de J. Majon, savant chémiste de Gènes, les aiguilles non-aimentées acquièrent par ce moyen, une sorte de polarité magnétique." The work containing this passage was lent to Mr. Sabine by Mr. Latimer Clark.

year he exhibited one of Baron Schilling's telegraphs in his lectures at King's College.

135. In 1836 Mr. William Fothergill Cooke saw in the lectures of Professor Muncke, at Heidelberg, the performance of a similar instrument. Struck by its obvious practical importance, he devised a system of telegraphy, and, in partnership with Wheatstone, dating from June, 1837, succeeded in introducing the telegraphic system into England.

136. From 1832 to 1836 Morse sought to apply chemical decomposition by the electric current to telegraphic purposes; he abandoned this for his electro-magnetic system devised in 1836. This method consists in stamping, by means of the attraction of an electro-magnet, dots and lines upon a slip of paper caused to move by proper mechanism over the circumference of a wheel.

137. In 1850 the first submarine cable was laid by Mr. Brett between Dover and Calais. It survived only a day. In 1851 another cable was laid down, which proved successful.

138. On the 5th of August, 1858, the submergence of the first Atlantic cable was completed, and messages were sent between England and America. The cable ceased to act on the 4th of September, or about a month after its submersion.

139. In 1865 the second Atlantic cable was laid and lost. In 1866 a cable was successfully laid, and in the same year the cable of 1865 was recovered. Messages are now sent between England and America at the rate of fourteen words a minute.

Phenomena observed in Telegraph-Cables.

140. Davy showed ('Elements of Chemical Philosophy,' 1812, p. 154) that a Leyden battery could be charged with voltaic electricity.*

* Davy thus describes the celebrated battery with which he made this experiment. The spirit to which the battery owed its birth has not diminished among the members of the Royal Institution:—"The most powerful combination that exists in which number of alternations is combined with extent of surface, is that constructed by the subscriptions of a few zealous cultivators and patrons of science, in the laboratory of the Royal Institution (in 1808). It consists of two hundred instruments, connected together in regular order, each composed of ten double plates arranged in cells of porcelain, and containing in each plate thirty-two square inches; so that the whole number of double plates is 2000, and the whole surface 128,000 square inches. This battery, when the cells were filled with 60 parts of water mixed with one part of nitric acid, and one part of sulphuric acid, afforded a series of brilliant and impressive effects. When pieces of charcoal about an inch long and one-sixth of an inch in diameter, were brought near each other (within the thirtieth or fortieth part of an inch,) a bright spark was produced, and more than half the volume of the charcoal became ignited to whiteness, and by withdrawing the points from each other a constant discharge took place through the heated air, in a space equal at least to four inches, producing a most brilliant ascending arch of light, broad, and conical in form in the middle. When any substance was introduced into this arch, it instantly became ignited; platina melted as readily in it as wax in the flame of a common candle; quartz, the sapphire, magnesia,

141. Dr. Werner Siemens was the first to employ (in 1847) gutta-percha as a means of insulating subterranean telegraph wires. On the 18th of January, 1850, in a paper communicated to the Physical Society of Berlin, he stated that a subterranean wire covered with gutta-percha, and surrounded by the moisture of the earth, behaved like a colossal Leyden-jar. He also found that ordinary telegraph wires charged themselves, though in a much smaller degree than the subterranean wires.

142. In 1838 Faraday predicted the retardation of the electric discharge by its own inductive action. ('Experimental Researches', 1333. 'Faraday as a Discoverer,' New Edition, p. 89.)

143. In 1854 Faraday experimented with cables at the gutta-percha works of the Electric Telegraph Company. One hundred miles of gutta-percha covered wire were immersed in water, and a second hundred miles of a similar wire were placed in a dry tank. We will call the former the water wire, and the latter the air wire.

144. Connecting one pole of a battery with the earth, and connecting the other pole with one of the two insulated ends of the water wire, on breaking the connection and touching the wire a powerful shock was received; the discharge from the wire was also competent to ignite a Statham fuze. When, after having been in contact with the battery, the wire was separated and connected with a galvanometer, the instrument was powerfully affected.

145. A rush of electricity into the wire was declared by the galvanometer when contact was made; a rush out of the wire was declared when the wire between the battery and the galvanometer was

lime, all entered into fusion; fragments of diamond, and points of charcoal and plumbago, rapidly disappeared, and seemed to evaporate in it, even when the connection was made in a receiver exhausted by the air-pump; but there was no evidence of their having previously undergone fusion.

"When the communication between the points positively and negatively electrified was made in air, rarefied in the receiver of the air-pump, the distance at which the discharge took place increased as the exhaustion was made, and when the atmosphere in the vessel supported only one-fourth of an inch of mercury in the barometrical gauge, the sparks passed through a space of nearly half an inch; and by withdrawing the points from each other, the discharge was made through six or seven inches, producing a most beautiful coruscation of purple light, the charcoal became intensely ignited, and some platina wire attached to it, fused with brilliant scintillations, and fell in large globules upon the plate of the pump. All the phænomena of chemical decomposition were produced with intense rapidity by this combination. When the points of charcoal were brought near each other in nonconducting fluids, such as oils, ether, and oxymuriatic compounds, brilliant sparks occurred, and elastic matter was rapidly generated; and such was the intensity of the electricity, that sparks were produced, even in good imperfect conductors, such as the nitric and sulphuric acids.

"When the two conductors from the ends of the combination were connected with a Leyden battery, one with the internal, the other with the external coating, the battery instantly became charged, and on removing the wires, and making the proper connections, either a shock or a spark could be perceived; and the least possible time of contact was sufficient to renew the charge to its full intensity."

connected with the earth. None of these effects were observed with the 100 miles of air wire.

146. Faraday, like Werner Siemens, rightly explained the effect by likening the cable to an enormous Leyden-jar, the wire constituting the interior, the water the exterior coating, with the gutta-percha insulator between them. In fact, the surface of the wire in these experiments amounted to 8300 square feet, while the surface of the outer coating of water was 33,000 square feet. To the charge and discharge of this apparatus the effects observed were due.

147. In a subterranean line of telegraph 1500 miles long were placed three galvanometers: one, *a*, at the beginning of the wire; a second, *b*, in the middle; and a third, *c*, at the end, which was also connected with the earth.

148. Connecting the battery with the wire of the galvanometer *a*, that instrument was instantly affected; after a sensible time *b* was affected; and after a still longer time *c*. It required, in fact, two seconds for the electric stream to reach the last instrument.

149. All the instruments being deflected, when the battery was suddenly cut off at *a*, that instrument instantly fell to zero, *b* fell subsequently, and *c* after a still longer interval.

150. By a brief touch of the battery-pole against *a*, that instrument was deflected, and could be allowed to fall back into its neutral condition before the electric power had reached *b*; *b* in its turn would be affected, and left neutral before the power had reached *c*.

151. In this case a wave of force was sent into the wire which gradually travelled along it, appearing in different parts of the wire at successive intervals of time.

152. It was even possible, by adjusted touches of the battery, to make several successive waves co-exist in the wire.

153. When, after making and breaking contact at *a*, that galvanometer was connected with the earth, part of the electricity sent into the wire returned, and deflected *a* in the reverse direction; here currents flowed in opposite directions out of both extremities of the wire.

154. These effects of induction enabled Werner Siemens and Faraday to explain the widely different velocities assigned by different experimenters to the electric current.

155. To pass through any conductor electricity requires time, the time being directly proportional *to the length* of the conductor.

156. But in the case of a submarine cable another cause of retardation comes into play, namely, the charging of the cable; the retardation here is proportional *to the square of the length* of the cable.

Artificial Cables.

157. It was to illustrate points like these and to determine the dimensions to be given to the Atlantic cables, that Mr. Cromwell Varley devised his artificial cables.

158. In one of these cables a resistance equal to that of a real cable 14,000 miles in length is obtained by introducing into the path of the current feebly-conducting liquids instead of metallic wires. The inductive action is obtained by means of condensers of tin-foil. In another artificial cable coils of wire are employed to give the necessary resistance.

159. The arrangement described in Note 81 is a condenser. But those constructed by Mr. Varley are of enormously greater area, the condensing sheets being separated from each other not by plates of glass, but by thin sheets of paper and paraffine. The vastness of the area and the proximity of the inducing surfaces combine to exalt the effect.

160. When the condensers themselves are charged by a battery, on discharging them they exhibit phenomena similar to those of a Leyden-jar. The shock, spark, and other effects of frictional electricity are readily obtained.

161. A series of 50 condensers, for example, joined "in cascade," that is to say, with the outer coating of each joined to the inner coating of the next, when charged with a battery of 1000 cells yield powerful sparks, and deflagrate wires.

162. If the wire be bent and introduced into a glass of water, the glass is shattered by the discharge.

163. In the 14,000-mile artificial cable are introduced a series of eleven tubes containing the resisting liquid. Into these dip wires. One end of the charging battery is connected with the earth, and the other end can, at will, be connected with the artificial cable. A series of ten galvanometers are placed between the resisting tubes along the artificial cable.

164. When no condensers are employed, on making connection with the battery all the galvanometers appear to be simultaneously deflected.

165. When a condenser is introduced between each pair of resisting cells—ten condensers in all—the current has to charge each condenser to a certain degree before it can sensibly affect the galvanometer beyond the condenser. Hence, when the condensers are attached, the action on the galvanometers is successive, not contemporaneous.

166. Mr. Varley supposed his 14,000-mile artificial cable divided into sections representing stations in London, at Gibraltar, Malta, Suez, Aden, Bombay, Calcutta, Rangoon, Singapore, Java, and Australia. Supposing an actual cable laid, and galvanometers placed at these stations, the deflections obtained on establishing battery contact would be successive. They are represented by the deflections of the galvanometers associated with the artificial cable.

167. By varying the resistance and the amount of inductive condenser-surface a representation of any other cable may readily be produced.

168. Connected with the needle of each of the ten galvanometers is a reflecting mirror, from which a brilliant spot of light is cast upon a screen. When the cable is not in action, the ten spots form a row along the same vertical line: when the battery contact is made, the successive deflections of the galvanometers is declared by the successive motion of the spots.

Sketch of Ohm's Theory and Kohlrausch's Verification.

169. I have already spoken (Note 110) of the force which urges forward the electric current (the electro-motive force). The amount of this force may be deduced from the action of the current, when opposed by different resistances, upon a freely suspended magnetic needle.

170. If the wire which carries the current be cut across, the current ceases to flow. The electricity ceases to be *dynamic.* But at the two ends of the severed wire we have *static* electricity.

171. By suitable instruments the amount of this statical charge may be determined; it increases with the number of elements of the battery.

172. It is, moreover, proportional to the strength of the current obtained when the wires are reunited.

173. In this way the statical charge becomes a measure of dynamical action: electricity at rest is connected with electricity in motion.

174. In experiments on the electroscopic properties of the voltaic circuit it is necessary that the battery should be well insulated.

175. If the middle point of a wire which connects the two poles of a voltaic battery be connected with the earth, the tension of that point is null. The circuit gradually rises in tension right and left to the two poles of the battery. But on one side of the point we have exclusively positive electricity, while at the other side we have exclusively negative electricity.

176. At equal distances, at opposite sides of the zero point, the tension is the same.

177. If any other point than the middle be connected at the earth, it becomes the zero point, right and left of which as before we have the two opposite electricities.

178. If the negative end of the battery be connected with the earth the whole wire shows positive electricity; if the positive end be connected with the earth the whole wire shows negative electricity.

179. The wire offers a certain resistance to the passage of the current. The battery itself is also in the circuit, and the current has to overcome its resistance also. But the resistance of the battery may be expressed by a certain length of the external wire. When this is done the sum of the lengths of both wires is called the *reduced length* of the circuit.

180. Given the reduced length of the circuit and the electro-motive force, we can determine by a simple calculation the electric tension of every point in the circuit.

181. The circuit through which the current flows may be represented by a horizontal line (called an abscissa); the electric tension at every point of the circuit may be represented by a vertical line (called an ordinate). If ordinates be drawn to represent the electric tensions at a great number of points of the circuit, the line joining the ends of all the perpendiculars will represent the distribution of electric tension in the circuit. The *steepness* of this line also represents what Ohm called the *electric fall.*

182. More strictly, the electric fall is the decrease in the length of the ordinate for the unit of length of the abscissa.

183. The total charge of the wire is expressed by the area of the triangle enclosed by the ordinate, abscissa, and line of fall.

184. The laws of the voltaic circuit, as enunciated by Ohm, have been verified everywhere. The electroscopic state of the circuit has been examined by Kohlrausch, and found to be in strict accordance with Ohm's theory.

185. Ohm assumed the passage of the electric fluid from one section to another of the connecting wire to be due solely to the difference of electric tension between the two sections; he further assumed the quantity of electricity transmitted to be proportional to this difference of tension, and from these fundamental assumptions he deduced the laws of the voltaic circuit.

186. These laws may be briefly stated thus:—

a. The strength of the current is directly proportional to the electro-motive force.

b. The strength of the current is inversely proportional to the resistance.

c. If the wire which unites the two poles of battery be of the same material, and of the same thickness throughout, the "electric fall" is the same throughout the wire.

d. If the wire be of the same material, but of different thicknesses, the "fall" is steeper on the thin wire than on the thick. The "fall" is inversely proportional to the cross-section of the wire.

e. If the poles be connected by two wires of the same thickness, but of different resisting powers, the electric fall is steepest on the more resisting wire. The "fall" is directly proportional to the specific resistances of the wires.

187. In verifying these laws, Kohlrausch employed a condenser to augment the feeble charges obtained from his voltaic cell, and he held this instrument to be essential. By an exceedingly skilful device Sir Wm. Thomson has rendered the condenser unnecessary, and has thus greatly simplified the means of demonstration.

Electro-chemistry.

Chemical Actions in the Voltaic Cell: Origin of the Current.

188. Philosophers suppose matter to be made of elementary parts called atoms, which are practically indivisible.

189. The elementary atoms can be caused to unite to form compound atoms, which are called molecules.

190. Thus, water is formed of the combination of the atoms of oxygen and hydrogen; common salt is formed of union of atoms of chlorine and sodium; potash is formed by the union of the atoms of potassium and oxygen; the sulphuric acid, also, which we employed to acidulate our water is formed by the union of atoms of sulphur with atoms of oxygen.

191. When, as in our first experiment, two strips of zinc and platinum are dipped into acidulated water, the zinc, as we know, exerts a very strong attraction on the oxygen of the water. When the strips are united, this attraction triumphs; the oxygen unites with the zinc, and a voltaic current is established.

192. The oxide of zinc here formed combines with the sulphuric acid, and forms sulphate of zinc.

193. By this removal of the oxide from its surface the zinc is kept constantly clean, and thus enabled to attract other atoms of oxygen from the surrounding liquid. During this process the zinc gradually dissolves, and as long as this continues the electric current will flow. In fact, it is the constant dissolution of the zinc that maintains the permanent current.

194. The hydrogen of the water, as we have seen, escapes as a free gas from the surface of the platinum, which, unlike the zinc, is not dissolved.

195. We are not yet quite clear as to the precise way in which the electric current is supported by the solution of the zinc, but the following facts and speculations ought to be known to you.

196. When two different metals are brought into contact, with no liquid between them, one of them charges itself with positive and the other with negative electricity. We have here the famous "contact force" which Volta and his followers considered to be the urging power of the voltaic current.

197. But the generation of heat, and the performance of mechanical work, by the mere contact of two metals, would be equivalent to a perpetual motion. It would be at variance with the law which requires for the production of any power an equivalent consumption of some other power.

198. It is, however, a fact that when two different metals touch each other, the positive electricity resorts by preference to one metal, and the negative electricity to the other; the two electricities are, as it were, attracted differently by the two metals.

199. This difference of attraction, however, only causes a momentary re-arrangement of the two electricities, which pass, when the contact is made, into a new condition of equilibrium. As long as the contact continues this equilibrium is not disturbed; there is no continuous current.

200. We may regard the distinct atoms which enter into the molecules of a compound as charged in a similar manner. For example, the atoms of hydrogen and oxygen when they unite to form a molecule of water, may be looked upon as charged like the two touching metals. This would be the case if the atoms, like the metals, possessed different attractions for the two electricities.

201. When strips of zinc and platinum are plunged in such a liquid, the positively charged atom will turn towards the one metal, and the negatively charged atom towards the other.

202. But, unless the metals touch each other, electrical equilibrium immediately sets in, a constant state of electric tension being set up at the free ends of the two metals.

203. The electricity at the ends may be permitted to flow into a condenser, and may be thus stored up; such a condenser may then be discharged through a covered wire which passes round a magnetic needle, a deflection of the needle being thus produced.

204. Thus in Davy's experiment with his large voltaic battery, wherewith he charged his battery of Leyden-jars, the latter, after having been charged, might be discharged through a galvanometer, a magnetic deflection being thus produced.

205. But the metals, once relieved of their charge, would immediately reload themselves with electricity, and might be again employed to charge a Leyden battery, and to produce a deflection of a magnetic needle.

206. At no moment during this process the battery circuit would be complete; still we should have a succession of magnetic actions similar to those observed with a closed circuit.

207. In fact, in the closed circuit the solution of the zinc incessantly removes the charged surface of that metal by dissolving it away, and enables the zinc to take a fresh charge; an incessant effort, never fully satisfied, is made to establish electric equilibrium; the incessant renewal of the effort maintains the electric current.

Chemical Actions at a Distance: Electrolysis.

208. Thus, then, in the cell where the voltaic current is generated chemical action occurs. We have, on the one hand, the decomposition of the water, and on the other the combination of the zinc with the oxygen and the sulphuric acid.

209. But a voltaic current can also produce chemical action at a distance from its place of generation. This discovery, as stated in Note 127, was made in the year 1800 by Nicholson and Carlisle.

210. We cannot decompose water by a single voltaic cell; but when two or more cells are united to form a battery, the current from such a battery, when sent through acidulated water, tears asunder the united atoms of oxygen and hydrogen.

211. The oxygen is set free at the place where the current enters; the hydrogen is set free at the place where the current quits the liquid. If the direction of the current be reversed, the oxygen and hydrogen instantly change places.

212. It must be clearly borne in mind that the direction of the current, as already defined, is the direction in which the positive electricity moves. Knowing, therefore, the places at which the oxygen and hydrogen are liberated, we can infer with certainty the direction of the current through the liquid.

213. For every volume of oxygen liberated in the decomposition of water by a voltaic current, two volumes of hydrogen are set free.

214. Electro-chemical decomposition is called *electrolysis;* and the compound liquid decomposed by the electric current is called an *electrolyte.*

215. The electric current formed a powerful means of analysis in the famous experiments of Sir Humphry Davy in 1807.

216. By operating with the current upon ordinary potash, Davy found the base of this substance to be a metal of exceeding lightness, and with an extraordinary appetite for oxygen. When placed on water, it floated on the liquid, and combined with its oxygen. By the heat thus generated the liberated hydrogen was caused to burst into flame. When a globule of the metal was placed on ice, it burned with a bright flame, and the hole made by the heat was filled with a solution of potash.

217. Soda, treated in the same manner, also yielded a metal resembling that of potash. Thus Davy, by the use of the voltaic current, decomposed the alkaline earths, and greatly expanded our knowledge of chemistry.

218. To obtain these effects it is necessary to bring the potash and the soda to a state of fusion by heat. In the solid state they are non-conductors of electricity. In fact, the molecules, when rigid, cannot turn in the manner indicated in Note 201. To conduct the current, it is necessary that they should thus turn and be decomposed.

219. When a current is sent through a solution of common salt, it decomposes both the water and the salt. The chlorine of the salt, in company with the oxygen of the water, appears where the current enters the liquid. The sodium of the salt, in company with the hydrogen of the water, appears where the current quits the liquid.

220. Chlorine possesses powerful bleaching properties; and if the solution of salt be coloured with indigo or litmus, the presence of the chlorine is declared by the destruction of the colour.

221. When a current is sent through a solution of iodide of potas-

sium, the brown substance iodine is set free where the current enters, while the metal potassium is set free where the current quits the solution. The experiment may be made by moistening bibulous paper with the dissolved iodide.

222. In electrolysis it is usual to immerse two plates of platinum, or of some other suitable substance, in the liquid to be decomposed, and to send the current from plate to plate. The plate at which the current enters the liquid is called the Positive Electrode, the plate at which the current quits the liquid is called the Negative Electrode. Without the liquid these electrodes would, as we have already learned, charge themselves with positive and negative electricity.

223. But inasmuch as electricities which attract each other are of opposite qualities, the substance which is liberated at the positive electrode is called the Electro-Negative constituent, while the substance liberated at the negative electrode is called the Electro-Positive constituent of the liquid.

224. Thus, in the examples above given the oxygen, chlorine, and iodine are the electro-negative elements; the hydrogen, sodium, and potassium being the electro-positive elements.

225. The terms electro-positive and electro-negative are, however, relative, for a substance may be electro-positive in one combination, and electro-negative in another.

226. If an electric current be conducted through a solution of sulphate of soda, it separates the sulphuric acid from the soda; the presence of the acid may be proved by its turning a vegetable colour red.

227. When nitrate of silver or acetate of lead is decomposed by a voltaic current, crystals of silver, or of lead, are deposited on the negative electrode.

228. The chemical actions of the electric current, some examples of which are here given, constitute what is called Electro-chemistry.

229. Electro-plating and gilding and the electrotype process are important applications of electro-chemistry. Here a chemical compound containing gold, silver, or copper is decomposed by a voltaic current, the metal being deposited on the surface intended to be coated with it.

230. If the surface on which the metal is deposited have a design engraved upon it, the lines of the engraving are accurately filled by the metal which, when the deposit is thick enough, may be detached, a perfect copy of the design being thus obtained.

Measures of the Electric Current.

231. The *tangent-compass*, devised by Weber, consists of a vertical ring of brass or copper, in the centre of which swings a small compass-needle. The ring being placed in the magnetic meridian, the needle is deflected when a current is sent round the ring. The strength of the

current can be proved to be proportional to the tangent of the angle of deflection; hence the name of the instrument.

232. The *voltameter* is an instrument devised by Faraday to measure the strength of an electric current. It consists of a graduated tube which receives and measures the quantity of gas generated by the current in a given time.

233. The strengths of a series of currents measured by the voltameter are accurately proportional to the same strengths measured by the tangent-compass. Placing a tangent-compass and a voltameter in the same series of circuits, the tangents of the angles observed in the one case are accurately proportional to the quantities of gas generated in the other.

Electric Polarization: Ritter's Secondary Pile.

234. When an electric current is sent through acidulated water a film of oxygen covers the positive electrode, and a film of hydrogen covers the negative electrode. One of these two substances being electro-positive, and the other electro-negative, they act in the liquid like two different metals; the hydrogen plays the part of zinc, and the oxygen plays the part of platinum.

235. Interrupting the primary battery circuit, and uniting together the two plates covered with their respective films, an electric current is obtained.

236. The direction of this current is from the hydrogen film to the oxygen film in the liquid, and from the oxygen film to the hydrogen film through the connecting wire.

237. Two electrodes thus covered with condensed gaseous films are said to be *polarized:* and the currents obtained from them are called currents of polarization.

238. Now the battery current being always from oxygen to hydrogen (see Note 211), it is plain that the current of polarization is always opposite in direction to the battery current employed to polarize the electrodes.

239. When a decomposition cell with platinum plates is introduced into a voltaic circuit, it is found that the battery current, though strong at starting, gradually sinks. This sinking is due to the gradual development of the antagonistic current of polarization.

240. Also in the cells of the battery itself this current of polarization may come prejudicially into play. When two metals, say zinc and platinum, and one liquid, say acidulated water, are employed, the platinum plate is coated with a film of hydrogen.

241. This hydrogen, being electro-positive, resembles a plate of zinc, so that when it is present we have, as it were, zinc opposed to zinc in the battery.

242. Were both plates actually of zinc we could have no current; and with the hydrogen film which approximates to zinc we have only a feeble current. To get the full effect of the zinc and platinum some means must be devised to remove from the platinum its film of hydrogen.

243. This is effected in Grove's battery by the employment of *two liquids.* The one is strong nitric acid, which contains the plate of platinum; the other is dilute sulphuric acid, which contains the plate of zinc. The nitric acid is placed in a vessel of porous earthenware, which becomes saturated with the liquid and allows the current to pass through it.

244. When the current passes, the hydrogen liberated at the platinum electrode in Grove's cell is instantly oxidized by the nitric acid, and prevented from forming a film upon the surface of the platinum.

245. If instead of employing a single decomposition cell and a single pair of platinum electrodes, we employ a series of such cells, and send the same current through them all, we convert every pair of such plates into an active voltaic couple; and if the number of such couples be great, effects of great intensity may be obtained.

246. If instead of using decomposition cells we simply employ a series of plates of the same metal, say a series of half-crowns, separated from each other by pieces of bibulous paper or by bits of cloth wetted with acidulated water; on sending a voltaic current through such a pile of plates, we liberate on one of the surfaces of each plate a film of oxygen, and on the other surface a film of hydrogen. These play the part of the two different metals in the pile of Volta.

247. The electro-motive force of such a pile may be far greater than that of the battery which charges it. It may produce a far more brilliant spark, and urge its current against resistances which would be quite insuperable to the original battery current.

248. The discoverer of this form of pile was Ritter; it is sometimes called *the secondary pile,* to distinguish it from the battery which charges it.

Faraday's Electrolytic Law.

249. When the self-same current is sent through a series of cells containing various compound liquids, the same amount of liquid is not decomposed in all cases.

250. Let the current be sent in succession through a series of cells containing water, oxide of lead, chloride of lead, iodide of lead, and chloride of silver; then taking them in the above order, the weights of the liquids decomposed are represented by the numbers 9, 111·5, 139, 230·5, 143·5.

251. The question now is, how are these weights of the respective substances divided between the two electrodes? Supposing the numbers

to express grains we should have the following division between the electrodes:—

At the positive electrode.				At the negative electrode.	
Water	8	grains oxygen	..	1·	grain hydrogen.
Oxide of lead ..	8	" "	..	103·5	grains lead.
Chloride of lead	35·5	" chlorine	..	103·5	" "
Iodide of lead ..	127	" iodine	..	103·5	" "
Chloride of silver	35·5	" chlorine	..	108	" silver.

252. Now these numbers express the combining proportions of the respective substances; by the electric current in all cases the law of combination as regards quantity is exactly inverted. The substances combine in equivalent proportions; they are decomposed in precisely the same proportions. This is the celebrated law of electrolysis discovered by Faraday.

253. In no case in the body of the electrolyte is any decomposition observed; in no case is any gas there liberated. The substances set free appear at the electrodes, and there alone.

254. Taking water as an illustration, the process is to be figured thus:—When the electrodes, charged with electricity from the battery, are plunged into the liquid, the oxygen atom of the water turns towards the positive, and the hydrogen atom towards the negative electrode.

255. If the electro-motive force be strong enough, the oxygen is torn away from its hydrogen; the free hydrogen immediately converges its attraction on the next adjacent oxygen atom, and unites with it, dislodging at the same time the hydrogen with which that atom had been previously combined. Another atom of hydrogen is thus liberated, which in its turn decomposes the adjacent water molecule. Thus through the chain of molecules run a series of decompositions, followed by immediate recompositions, until the negative electrode is reached. Here the hydrogen, having no further oxygen with which to combine, is liberated as a gas. This is the theory of Grotthuss, which at all events fairly embraces the facts.

Nobili's Iris Rings.

256. The hardness of steel in tempering it is judged by its colour, which is due to a film of oxide overspreading the steel. The oxide which forms on the surface of molten lead also shows vivid colours.

257. These are the colours of *thin plates* investigated by Newton and explained by Thomas Young.

258. By electro-chemical decomposition Nobili produced such colours in a very beautiful manner. Placing, for example, a polished steel plate in a dilute solution of acetate of lead, and connecting the plate with the positive pole of a voltaic battery, on dipping the end of a wire connected with the negative pole into the solution, the peroxide of lead is liberated on the surface of the steel immediately

under the wire; and a film gradually diminishing in thickness spreads from that point outwards. Round this point we have a series of concentric circles showing vivid iris colours.

259. These colours, like all those of thin plates, depend upon the thickness of the film, which diminishes as the distance traversed by the current increases.

(Du Bois-Reymond has shown that when the point from the negative end of the battery is very near the steel plate, the thickness of the film corresponding to the different circles is inversely proportional to the cubes of their radii.)

Distribution of Heat in the Circuit.

260. When the two ends of a voltaic battery are connected by a thick wire of good conducting material, the wire is not sensibly heated; the heat due to the oxidation of the zinc is in this case confined to the battery itself.

261. But if the two ends of the battery be connected by a wire that offers a resistance to the current, the wire is heated, and may, if properly chosen, be raised to a white heat.

262. Considering the battery as the hearth where the zinc is burnt, we might be led to infer that the heat due to the combustion of the zinc is liberated on the hearth itself, and that its amount depends solely upon the quantity of zinc consumed.

263. This, however, is not the case. Let the battery, with its two ends united by a thick wire, be surrounded by a vessel of water, to which the heat developed by the oxidation say of an ounce of zinc is communicated; the quantity of heat developed is measured by the rise of temperature of the water.

264. Let the battery, with its two ends united by the resisting wire, be placed in the same vessel, and let the heat generated in the battery by the oxidation of an ounce of zinc be again determined; this heat will be less than that observed in the last experiment.

265. If the connecting wire be now enclosed in a separate vessel, and if the heat generated in the wire be thus determined, on adding this amount of heat to that liberated in the battery, a total heat is obtained exactly equal to that generated in the battery alone, when the good conducting wire was employed.

266. In fact, the absolute amount of heat generated by the oxidation of an ounce of zinc is perfectly constant; but it may be distributed in various proportions between the battery and the external circuit.

Relation of Heat to Current and to Resistance.

267. On what does the heat developed in a wire uniting the two ends of a voltaic battery depend?

268. It depends, in the first place, on the strength of the current, but it is not simply proportional to that strength.

269. Let the strengths of a series of currents, determined either by the tangent-compass or the voltameter, be represented by the numbers 1, 2, 3, 4, then the quantities of heat developed in the same wire by these respective currents are expressed by the numbers 1, 4, 9, and 16.

270. The heat generated is therefore proportional to *the square* of the strength of the current.

271. Preserving the strength of the current constant, the heat generated is proportional to the electrical resistance of the wire through which it passes. These important principles were established by Joule.

272. Thus, if one of two equal currents pass through a silver wire, and the other through a platinum wire of the same length and thickness, the heat generated in the platinum will be ten times that generated in the silver, because the resistance of the former is ten times that of the latter. To urge the current through the platinum in this case would, however, require greater battery power than that necessary for the silver.

273. Hence, when *the same current* is sent through a wire composed of alternate lengths of silver and platinum of equal thickness, the platinum spaces may be raised to a white heat, while the silver is not raised to the faintest glow.

Magneto-Electricity: Induced Currents.

274. In a conductor near to, but not in contact with, a voltaic circuit, a current is aroused when the circuit is *established*. When the circuit is *interrupted* a current is also aroused in the conductor.

275. Thus, supposing the voltaic circuit to be bent into the shape of a ring; and that a second ring, not in the circuit, is placed near the first: at the completion, and at the interruption, of the circuit a current will run round the second ring.

276. The two currents in the second ring are called *secondary* currents. They are of momentary duration. They impart, in passing, a shock to a magnetic needle round which they are sent, and by the motion of which their existence is demonstrated. But they vanish immediately, being quenched by the resistance of the ring, and converted into heat.

277. These two momentary currents flow in opposite directions through the ring. The secondary current, excited on making the circuit, is opposed in direction to the primary exciting current; that started on interrupting the circuit flows in the same direction as the primary.

278. These secondary currents are called *induced currents.* They were discovered by Faraday in 1830, and described by him in his Philosophical papers for 1831.

279. If, instead of employing a single ring, we make use of an electro-magnetic helix, every coil of the helix will furnish its quota of current, and the sum total of effect is much greater than when only a single ring or coil is employed.

For the following experiments, two flat spirals, each formed of covered copper wire, are used.

280. One of the spirals is laid flat upon a table, its two ends being connected with a galvanometer; the other spiral is connected with a voltaic battery, with which the connexion can be established or broken at pleasure. Let us call this the *inducing* or *primary* spiral, and that connected with the galvanometer the *secondary* or *induced* spiral.

281. Laying one spiral upon the other, on sending a current through the primary, the needle of the galvanometer is suddenly driven aside by the current induced in the secondary; but the force which acts upon the needle passes away in an instant, the needle returning to its first position.

282. On interrupting the current the needle also receives a shock, being deflected in the opposite direction. It thus declares the existence of a second temporary current in the secondary spiral. The directions of these two currents, with reference to that of the primary, have been already indicated; Note 277.

283. Holding the secondary spiral at a distance from the primary with the current flowing through the latter; on causing the secondary spiral *to approach* the primary, a current is aroused; this current ceases the moment the motion towards the primary ceases.

284. On *withdrawing* the secondary spiral from the primary, a current is also aroused; this current also ceases the moment the motion of withdrawal ends.

285. The current excited by approach is opposed in direction to the primary; the current excited by withdrawal is in the same direction as the primary.

286. Two electric currents flowing in the same direction attract each other; if they flow in opposite directions they repel each other.

287. Hence, to make the secondary spiral approach its primary, we have to overcome a *repulsion;* while to withdraw the secondary from the primary we have to overcome an *attraction.* Thus in order to produce these induced currents *we must expend mechanical force.*

288. The force thus expended appears as heat in the secondary wire after the cessation of the induced current. It is the mechanical equivalent of that heat.

289. The approach of a magnetic pole to the secondary spiral and the withdrawal of the pole from the same spiral also arouse induced currents. But, as before, it is only during the periods of approach and withdrawal that the current appears.

290. Thus by the mere motion of a magnet, and without any battery or machine, electric currents may be produced.

291. Every change of the magnetic condition of the space near a secondary coil or within it, produces an induced current in the coil. If the change be an augmentation of magnetism the current is in one direction; if it be a diminution of magnetism the current is in the opposite direction.

292. When a long secondary coil surrounds a primary coil with a core of iron, by breaking and making the circuit of the primary in rapid succession, a series of powerful discharges may be obtained. An automatic apparatus is usually employed to make and break the circuit.

293. Such Induction Coils have been constructed with great skill by Ruhmkorff, and are therefore sometimes called Ruhmkorff's coils. Mr. Apps has recently produced induction coils of astonishing power.

294. The power of a coil depends mainly on the perfection of the insulation of its coils. The induced currents in a Ruhmkorff's coil may possess thousands of times the electro-motive force of the primary which excites them. They are able, for example, to overleap as sparks, distances thousands of times greater than that possible to the primary.

Relation of Induced Currents to the Lines of Magnetic Force. Rotatory Magnetism.

295. The foregoing phenomena and principles were all laid bare by Faraday. He also established most important relations between his induced currents and the lines of force surrounding a magnet. See Note 25.

296. He proved that when a conductor moves *along* the lines of force no induced currents appear; but that when it moves *across* the lines of force such currents are generated.

297. He proved, for example, that when a metal disk is caused to rotate so as to be tangent to the lines of force, no current appears; while when the disk, in its rotation, *cuts* the lines of force, currents flow along the disk, from the centre to the circumference, and from the circumference to the centre. Closed circuits are thus established in the disk.

298. This, in fact, is the "Magnetism of Rotation," discovered by Arago in 1820, which received complete explanation at the hands of Faraday.

299. Faraday showed that the lines of force of terrestrial magnetism suffice to produce induced currents when they are intersected by the rotating disk. In fact all the effects of magneto-electric induction may be obtained from the magnetism of the earth.

300. When a conductor rotates round an axis which is parallel to the lines of force it experiences simply the resistance due to the friction of the air; but if the axis of rotation be transverse to the lines of force, the rotation is retarded by the interaction of the magnet and the induced currents.

301. This retardation may become so powerful as instantly to arrest the rotation. If, for example, a cube or sphere of copper, suspended from a twisted string, be caused to spin, by untwisting, between the poles of an unexcited electro-magnet, it experiences the retardation due to air friction only; but on the supervention of the magnetic force the rotation is suddenly arrested. Faraday also showed that in passing a plate of copper rapidly to and fro between the magnetic poles you seem to be cutting cheese, though nothing is visible. It is as if pure space were a kind of solid.

302. If by mechanical means the conductor be compelled to rotate, or to move to and fro between the excited poles, it will be heated. Joule first demonstrated this; but a very striking demonstration of it was given by Foucault, who heated his celebrated gyroscope in this way. The heat is readily rendered sufficiently intense to melt fusible metal. Between the unexcited poles no effect of this kind is produced.

303. The repulsion set up by induced currents between the helices and the moving masses of iron in an electro-magnetic engine would of itself limit the practical application of electricity as a motive power. Nevertheless, though such engines speedily reach the limit of their action, the conversion of molecular force into mechanical effect may be rendered far more perfect than in the case of the steam-engine.

The Extra-Current.

304. If the secondary coil of a Ruhmkorff's machine have its ends united, the secondary circuit being then complete, the spark obtained in breaking the primary is small. On separating the two ends of the secondary the primary spark is instantly augmented.

305. The diminution of the spark is due to the reaction of the completed secondary circuit upon the primary. When the secondary circuit is interrupted this reaction ceases.

306. The primary circuit, in its turn, can, when complete, react upon the secondary. It *is* complete whenever contact is *made* by the automatic contact-breaker. A great enfeeblement of the secondary current is the consequence. When the primary circuit is interrupted the reaction does not exist; there is no enfeeblement, the full power of the secondary being developed. It is on this account that in Ruhmkorff's coil we obtain discharges *in a single direction* only, instead of discharges alternating in direction.

307. The reaction here referred to connects itself with what is called the *extra-current.*

308. When a current is sent through a single primary coil, the primary current excites in the wire which carries it a secondary current opposed in direction to the primary. The primary arouses an antagonist in its own path, which, however, immediately disappears.

309. When the primary circuit is broken, a secondary current of momentary duration and having the same direction as the vanishing primary, is evoked in the coil.

310. Each of the two currents evoked *in the primary circuit itself*, at the commencement and at the cessation of the primary current, has been called by Faraday an *extra-current.*

311. The spark obtained on breaking the primary circuit is augmented in brilliancy and power by the extra-current.

212. If a second circuit be associated with the primary; if, for example, two covered wires are wound round the same reel; on making one of them a primary circuit we have the brilliant spark due to the extra-current, *as long as the ends of the second coil remain unconnected.*

313. But the moment they are connected the extra-current in the primary circuit disappears; there is an instant reduction in the brilliancy of the spark.

314. This is an example of the reaction referred to in Note 304. By the closing of the secondary circuit the extra-current is formed *in it* instead of in the primary one. Here, in fact, the extra-current becomes an ordinary induced current; it is only so long as it remains in the primary circuit that its distinctive name is applied to it.

Influence of Time on Intensity of Discharge. The Condenser.

315. The intensity of the secondary current—its "discharging distance," for example—depends upon the rapidity with which the primary is interrupted.

316. I have already referred to the passage of particles between the two severed terminals of a circuit. By these particles the current may be kept up for a short time after the terminals have been disunited. A *gradual* dying away of the primary is the consequence.

317. But to produce the maximum secondary intensity it is necessary that the primary should be extinguished *at once.*

318. This is very effectually accomplished if the primary be broken between the poles of a strong magnet. The secondary spark may be thus made to overleap distances, vast in comparison with those possible to it when the rupture of contact occurs far away from the magnetic poles.

319. The magnet quenches immediately the stream of particles which accompany the spark. Thus, instead of being spread over a very sensible interval, the whole power of the primary is concentrated into an instant of time.

320. This concentration is announced by the loudness of the report of the primary spark. This augmentation of loudness was first observed by Page; it was explained by Rijke, who also exalted in the way here indicated the discharge of the secondary coil.

321. The injurious effect of the spark produced by the rupture of

contact in Ruhmkorff's coil is much diminished by the employment of a condenser, which is attached to the primary. It was introduced by Fizeau.

Electric Discharge through rarefied Gases and Vapours.

322. The electricity from the prime conductor of an electrical machine passes through the air in the form of a dense and brilliant spark, which produces a very audible report.

323. When the discharge passes through rarefied air the discharging distance is augmented, and by sufficiently rarefying the air the discharge may be caused to pass *silently*. It then fills the tube through which it passes with a rosy light.

324. This rosy light has the same origin as that of the Aurora Borealis: it is due to the nitrogen of the air.

325. Every attenuated gas has its own characteristic colour when traversed by the electric discharge. When examined by a prism the colour resolves itself into distinct bands, the nature of the gas may indeed be inferred from the analysis of its spectrum.

326. The discharge of the induction coil through attenuated media produces luminous effects similar to those produced by the electric machine.

327. The tubes containing the attenuated gases or vapours are usually called *vacuum tubes*. Through the tubes pass platinum wires which are fused into the glass, and between which the discharge passes.

328. Such tubes are produced in great perfection by Geissler, of Bonn, and are sometimes called Geissler's tubes.

329. Under certain circumstances, the luminous discharge is composed of distinct luminous strata separated from each other by dark intervals transverse to the direction of the discharge. These strata were first observed by Grove; they were observed independently and finely developed by Ruhmkorff.

330. The luminous strata were believed to arise from the intermittent action of the contact-breaker of the induction coil; but Gassiot produced them both with the electric machine, and with his battery of 3500 cells, where no contact-breaker is employed.

331. Every single discharge of the induction coil through a properly chosen medium resolves itself into a series of pulses, which declare themselves as a stratified discharge. Under similar circumstances the discharge from the voltaic battery also is resolved into a series of pulses which are declared by their stratifications.

Action of Magnets on the Luminous Discharge.

332. The luminous discharge is to all intents and purposes an electric current, and is acted on by a magnet like a wire carrying a current.

333. But the flexibility of the luminous current in rarefied gases enables the magnet to act upon it in a manner peculiarly interesting and instructive.

334. Placing, for example, a tube through which the luminous discharge is passing between the poles of an electro-magnet, by exciting the magnet the stream of light may be either deflected or wholly extinguished.

335. In the latter case, by interrupting the current passing round the magnet, or by lifting the tube out of the magnetic field, the luminous discharge is restored.

336. In certain cases, when the luminous discharge consists simply of a feeble glow, the supervention of the magnetic force draws a series of strongly illuminated strata from the positive terminal of the vacuum tube; when the magnetism is interrupted, these strata retreat again in succession, as if swallowed up by the positive pole. A number of exceedingly beautiful experiments of this character has been made by Gassiot.

337. It has been stated in Note 306 that the discharges from the induction coil proceed always in the same direction; hence in each vacuum tube we have a positive terminal or pole, and a negative terminal or pole.

338. When the light surrounding the negative terminal is subjected to a magnet, it ranges itself exactly along the lines of magnetic force; the light at the positive terminal shows no such action. This discovery is due to Plücker.

Magneto-electric Machines. Saxton's Machine. Siemens's Armature.

339. Faraday's discovery of Magneto-electricity was announced in 1831. In 1833 a machine was constructed by Saxton for the more copious development of magneto-electric currents.

340. In it copper-wire coils, within which were placed cores of iron, were caused to rotate before the poles of a powerful magnet.

341. On the approach of a coil to one of the poles of the magnet, a powerful current, whose direction depended on the nature of the pole, was induced in the coil. When the coil retreated from the magnetic pole, a current in the opposite direction was induced. This production of opposite currents by approach and withdrawal has been already referred to in Notes 283, 284.

342. By means of an instrument called *a commutator*, which reversed one of the induced currents at the proper moment, the opposite currents were caused to flow in the same direction.

343. The cores of soft iron and their associated coils constitute what is called an *armature*. In Saxton's armature the coils were wound *transversely* to the iron cores.

344. But by winding his coils *longitudinally*, or parallel to the axis of the core, and placing the armature so formed between the poles

of a series of horse-shoe magnets, Siemens obtained magneto-electric currents much more powerful than those of Saxon.

Wilde's Machine.

Things were in this state when, in 1866, Wilde made an important addition to our knowledge of magneto-electricity.

345. He conducted the current obtained by means of Siemens's armature round an electro-magnet, and found that the magnetism thus excited was far greater than that of the entire series of steel magnets employed to generate the magneto-electric current.

346. Thus, in one case, he found that whereas the series of permanent magnets taken collectively was competent to support a weight of 40 lbs. only, the electro-magnet which they excited sustained a weight of 1088 lbs.

347. To produce this effect, however, it was necessary that the armature of the magneto-electric machine should rotate with great rapidity.

348. But Wilde went farther. Forming his electro-magnet from a large plate of iron, and placing between its long poles a correspondingly long armature, similar in shape and construction to that of the magneto-electric machine, he obtained from this second armature currents of enormously greater power than those obtainable from the first.

349. These currents could in their turn be sent round a second electro-magnet, formed from a larger plate of iron. Furnished with a rotating armature, this second electro-magnet produced effects previously unknown. Rods of iron a quarter of an inch in thickness were fused by the currents, and they were also found competent, when discharged between carbon terminals, to produce a light of intolerable brilliancy.

Siemens's and Wheatstone's Machine.

350. The next great step in magneto-electricity was made simultaneously by Dr. Werner Siemens and Sir Charles Wheatstone.

351. Expressed generally, this discovery consists in exalting, by means of its own action, to a high pitch of intensity an infinitesimal amount of magnetism.

352. Conceive an electro-magnetic core with a very small amount of residual magnetism, which is never wholly absent when iron has been once magnetized. Let a secondary coil, with cores of soft iron, rotate before the poles of such a magnet. Exceedingly feeble induced currents will circulate in the secondary coil. Let these induced currents, instead of being carried away, be sent round the electro-magnet which produced them; its magnetism will be thereby exalted. It is then in a condition to produce still stronger currents. These also being sent round the magnet, raise its magnetism still higher; a more

copious production of induced currents being the consequence. Thus by a series of interactions between the electro-magnet and the secondary helix, each in turn exalting the other, the electro-magnet is raised from a state of almost perfect neutrality to one of intense magnetization.

353. When the magnet has been raised to this condition, other coils than those employed to magnetize it may be caused to rotate before, or between, its poles; the currents from these coils may be carried away and made use of, for magnetization, for chemical decomposition, or for the electric light.

354. The first magneto-electric machine used to produce a light sufficiently intense for lighthouses was constructed by Mr. Holmes. In it permanent steel magnets and rotating helices were employed. Mr. Holmes has lately constructed a very powerful machine on the principle of Siemens and Wheatstone.

Induced Currents of the Leyden Battery.

355. If a Leyden-jar, or battery, be discharged through a primary spiral, it evokes a current in a secondary spiral. With a strong charge this secondary current may be caused to deflagrate a foot of thin platinum wire.

356. If the current from the secondary spiral be led round a third spiral which faces a fourth; on discharging the battery through the primary spiral, the secondary in the third spiral acts the part of a primary, and evokes in the fourth spiral a *tertiary current.*

357. With another pair of spirals this tertiary current can be made to generate a current of the *fourth order;* this again, with another pair of spirals, a current of the *fifth order.* All these currents can impart shocks, ignite gunpowder, or deflagrate wires.

For the investigation of the Induced Currents of the Leyden Battery we are indebted to Professor Joseph Henry, Director of the Smithsonian Institution, and to Professor Riess, of Berlin.

THE END.

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